Beam Polarimetry with Taus for an Upgraded SuperKEKB

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Beam Polarization Motivation

- Beam polarization is being considered as a future upgrade to SuperKEKB
- A polarized electron beam would allow Belle II to make many precise measurements of electro-weak parameters. Including A_{LR} for e,μ,τ,c,b

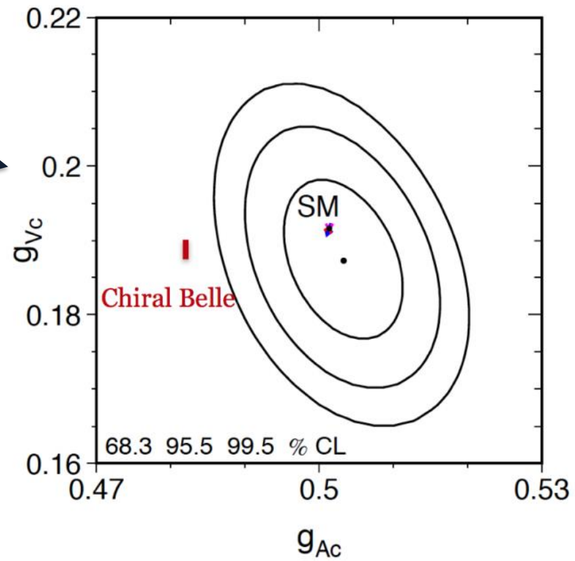
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_f s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle P \rangle \propto T_3^f - 2Q_f \sin^2\theta_W$$

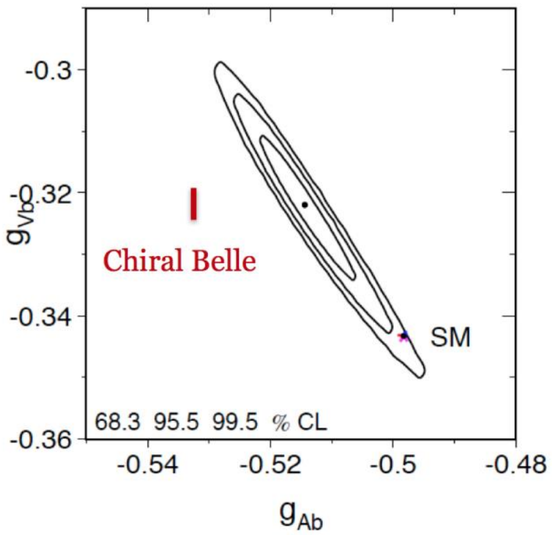
c-quark: **with 20 ab^{-1}** **b-quark:**

Chiral Belle ~7 times more precise

Chiral Belle ~4 times more precise

Red bars show expected +/- 1 sigma uncertainty





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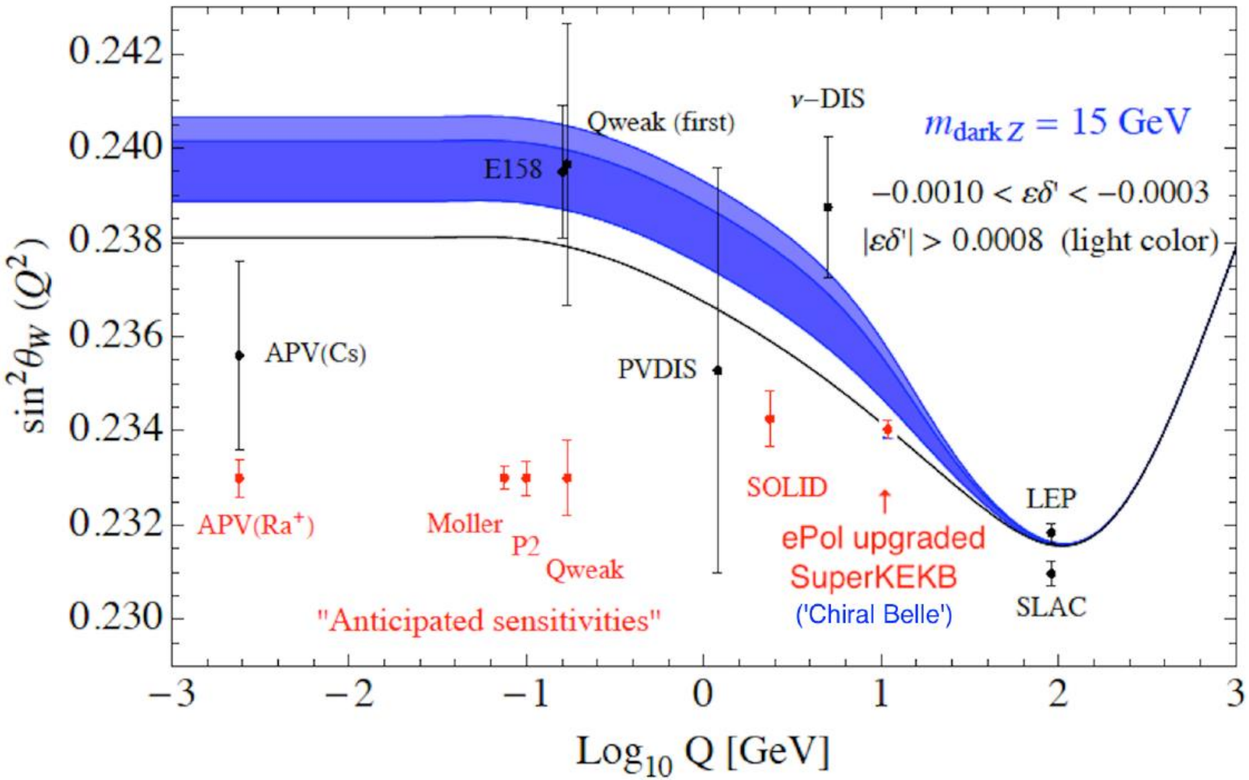

Red bars show expected sensitivity of future experiments

Chiral Belle expects: $\sigma(\sin_2\theta_W) \approx 0.0002$ (40 ab^{-1})

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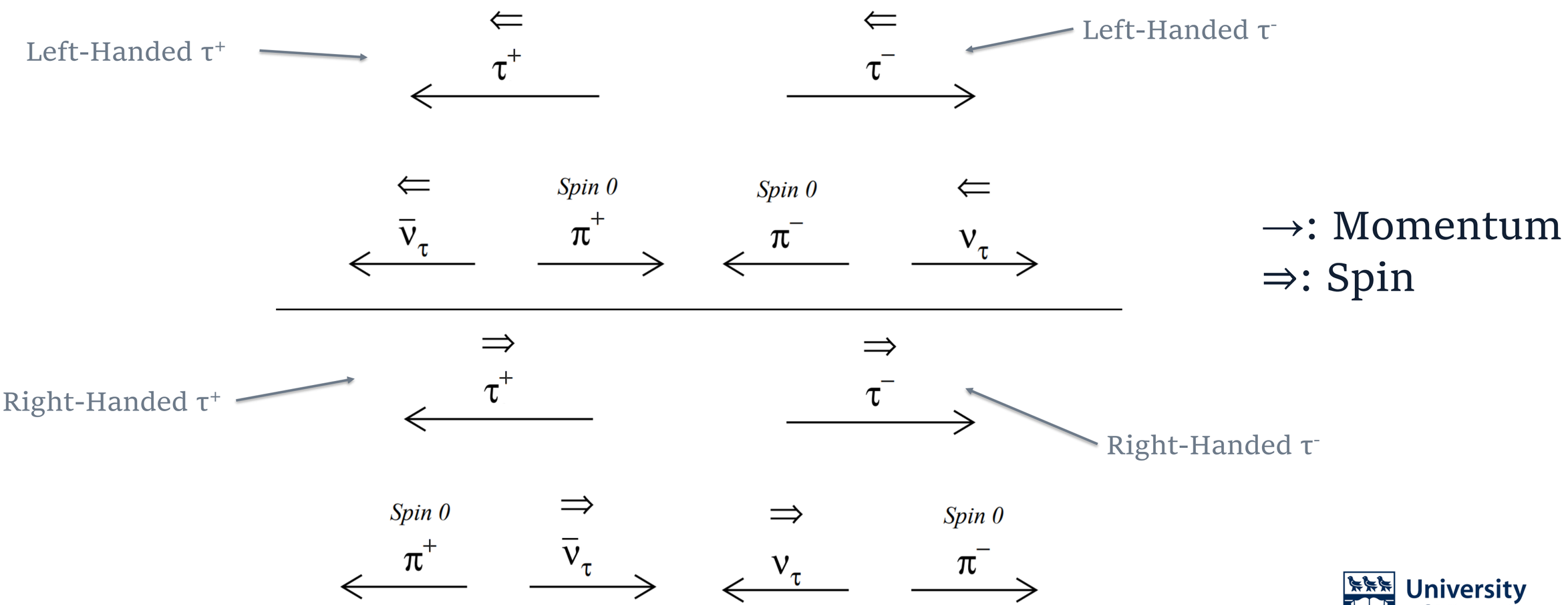
Polarization Sensitivity in Tau Decays

- The kinematics of the $\tau \to \pi\nu$ provide a powerful insight into the polarization



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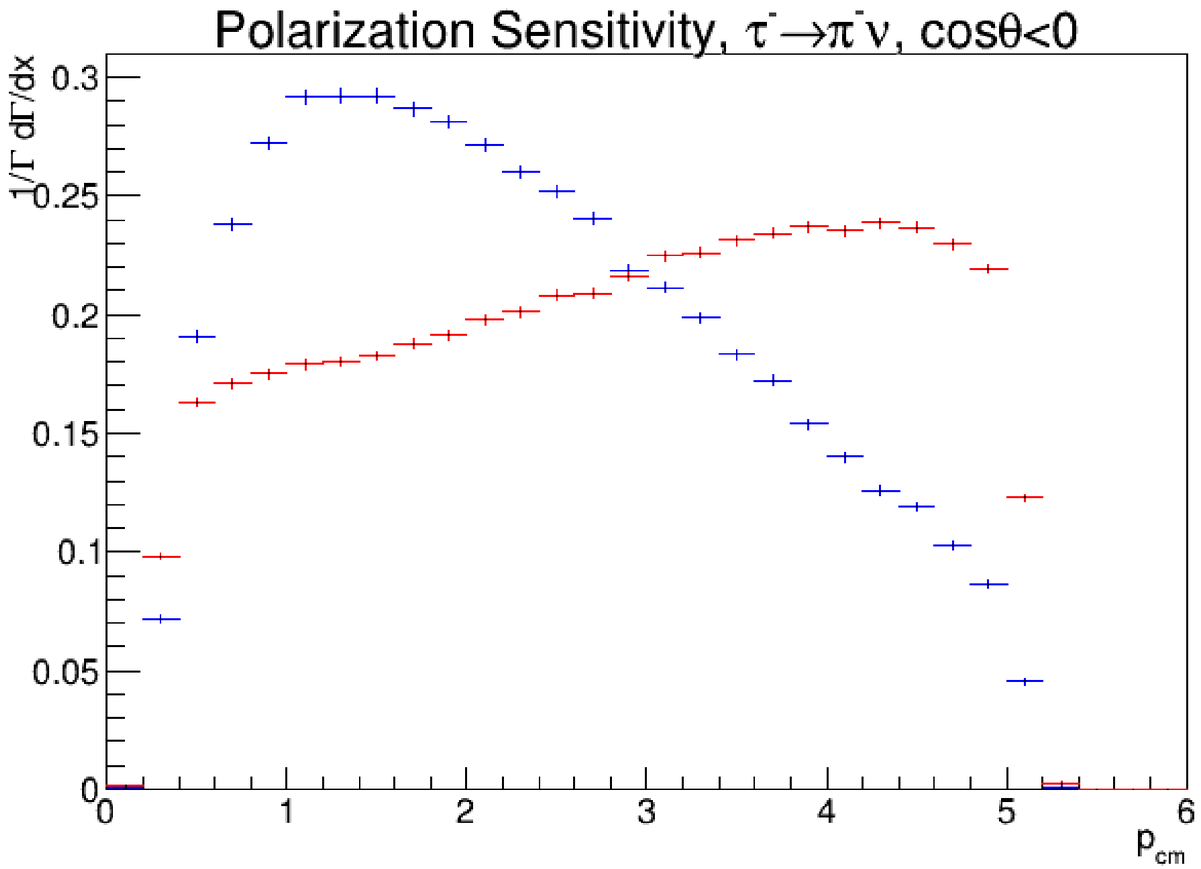
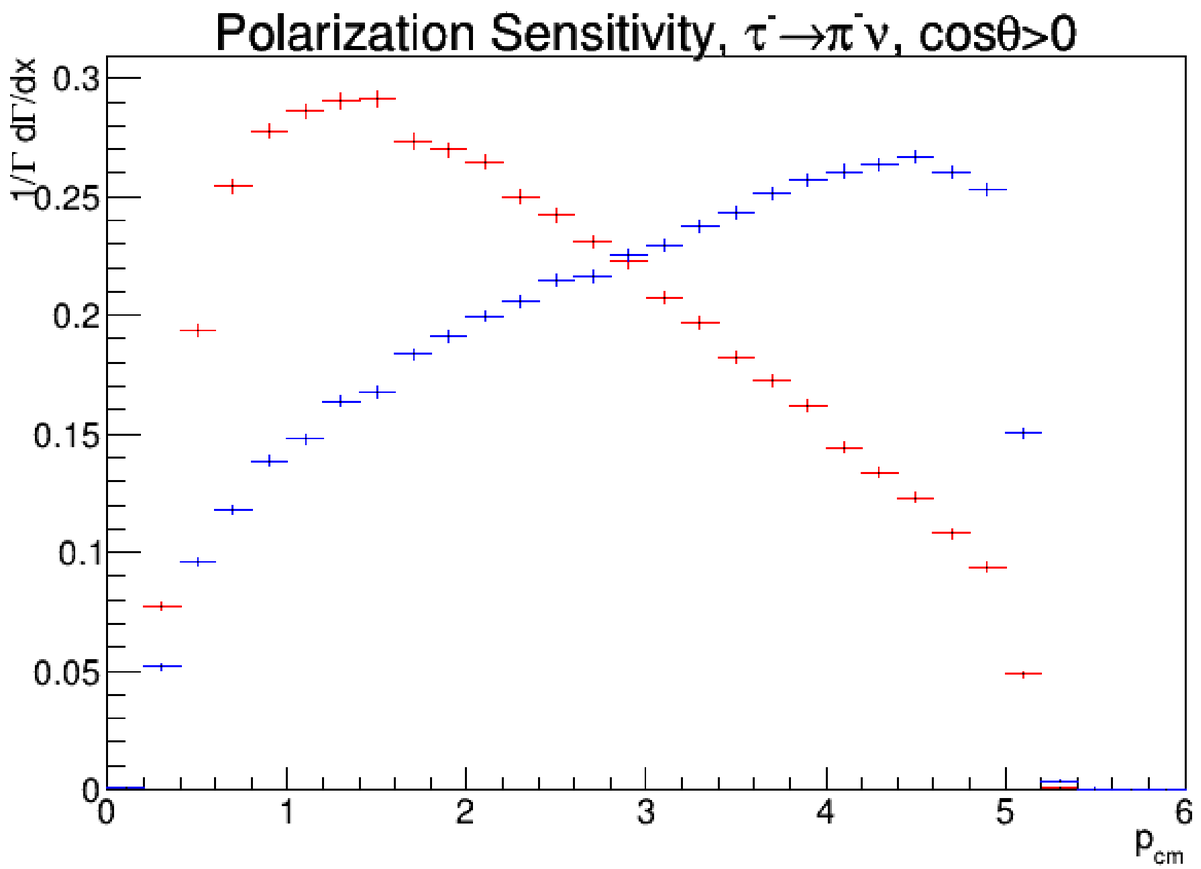
Pion Momentum, Polarization Sensitivity

- Polarization sensitivity is mirrored between the forward and backward region of the detector
- Theta is defined as the angle between the pion and the electron beam direction



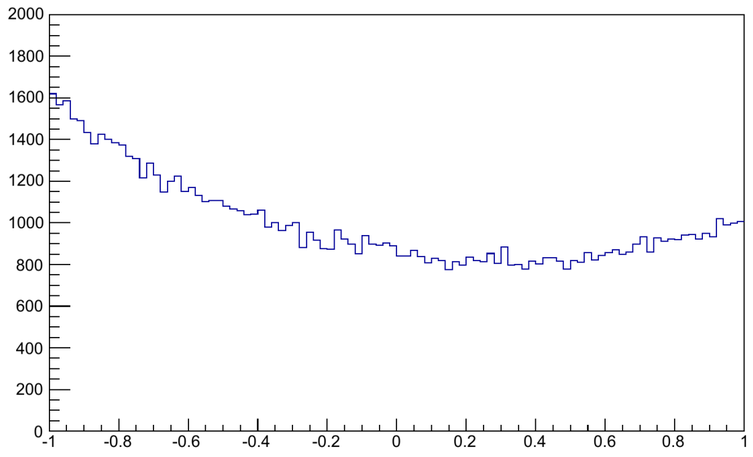


Red: Left-Handed e^- beam, Blue: Right-Handed e^- beam

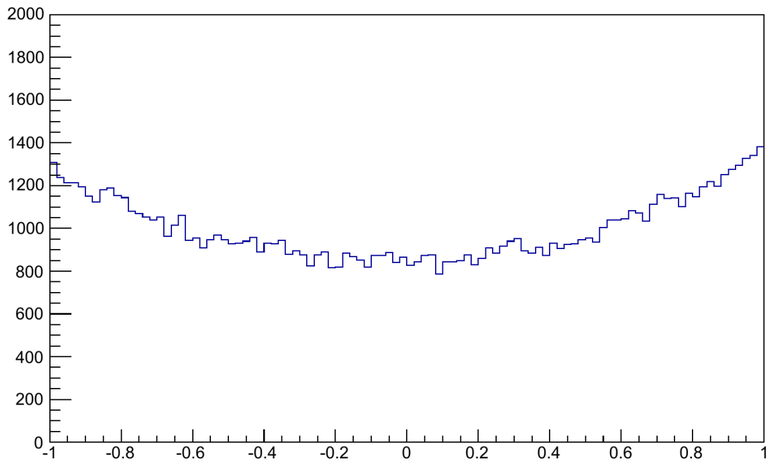
Pion Angular Distribution, Polarization Sensitivity

- Using momentum and cosθ gives together improves sensitivity

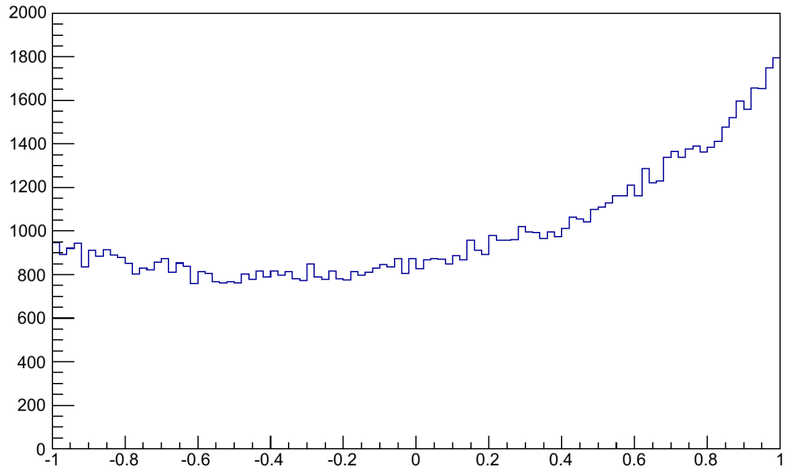
Left-handed e^- beam, π^- cosθ distribution



Unpolarized e^- beam, π^- cosθ distribution



Right-handed e^- beam, π^- cosθ distribution



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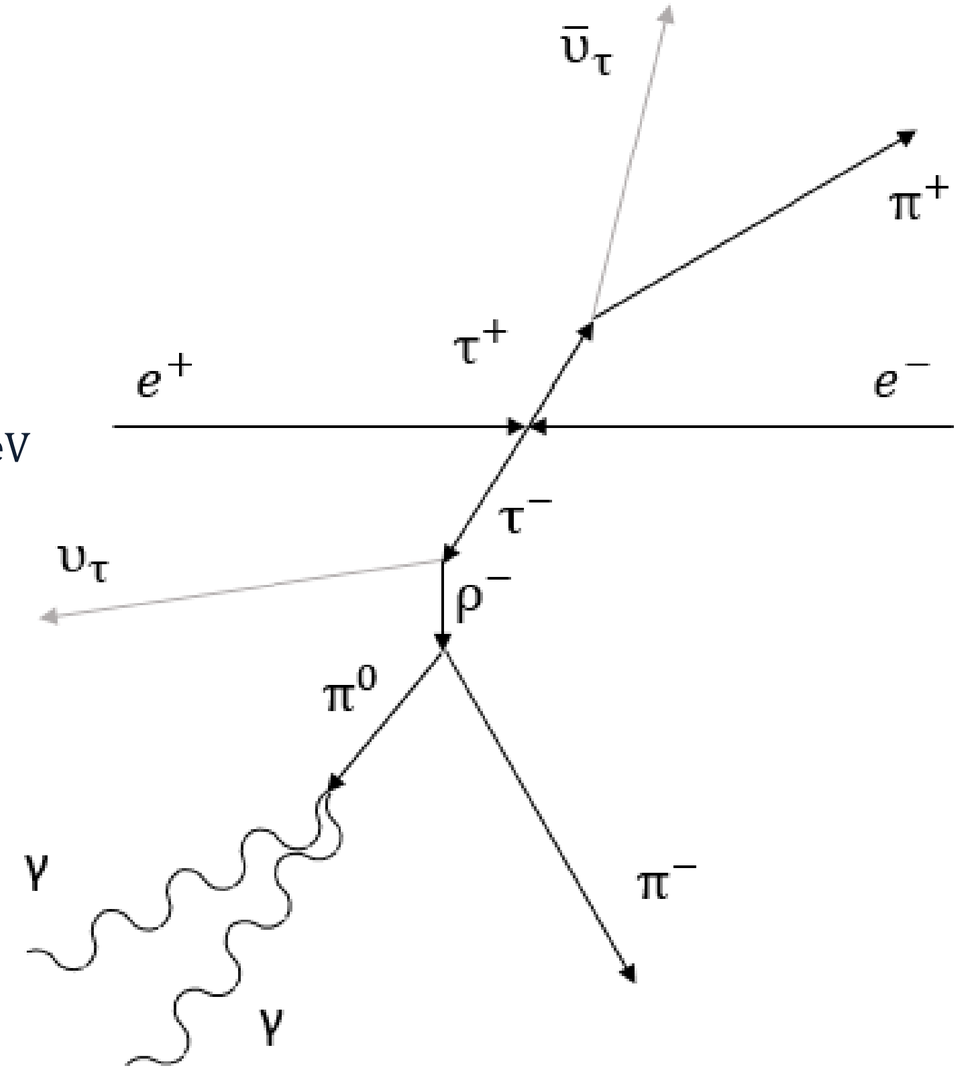
Event Selection

- We developed the technique on BaBar
  - Using 32.28 fb^{-1} as a blind sample (424.18 fb^{-1} On-peak data available)
- We tag tau events by $\tau^{\pm} \rightarrow \pi^{\pm} n\pi^{0}\nu$
  - One charged track, n π^0s in $115\ \text{MeV} < M_{\pi^0} < 155\ \text{MeV}$
- Signal is $\tau^{\pm} \rightarrow \pi^{\pm}\nu$
  - Require no neutrals in signal hemisphere
  - Fail muon and electron PID
- P_T>1.2 GeV to remove 2 photon backgrounds
- Gives 98% pure tau sample
- 60% $\tau^{\pm} \rightarrow \pi^{\pm}\nu$ decays



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Event Selection

- Largest background source is uds
- MC predicted number of events in the selected data sample

	Luminosity Scaled Events	Ratio
uds	4469	0.0167
$c\bar{c}$	113	0.0004
bhabhas	1051	0.0039
$\mu\mu$	27	0.0001
$\tau\tau$	262329	0.9789
$\tau \to e\nu\nu$	5366	0.0200
$\tau \to \mu\nu\nu$	45018	0.1680
$\tau \to \pi\nu$	163213	0.6090
$\tau \to$ else	48732	0.1818

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Polarization Fit

- We employ the Barlow&Beeston[1] template fit methodology
- MC and data is binned in 2D histograms of momentum vs cosθ
- Polarized tau MC was generated to be able to measure the polarization
- The unpolarized MC is split into 3 statistically independent sets to make 3 data-like samples
- The data (or data-like MC) is fit as a linear combination of the templates

$$D = a_l L + a_r R + a_b B + a_m M + a_u U + a_c C$$

$$\sum a_i \equiv 1$$

$$\langle P \rangle \equiv a_l - a_r$$

L=Left Polarized Tau MC, R=Right Polarized Tau MC, B=Bhabha(e^+e^-),M=μμ, U=uds, C=$c\bar{c}$

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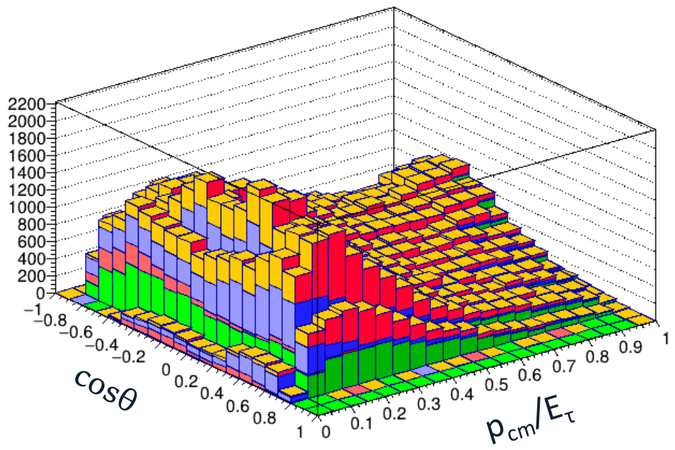
[1] R. Barlow, C. Beeston; Computer Physics Communications, Volume 77, Issue 2, 1993, Pages 219-228, https://doi.org/10.1016/0010-4655(93)90005-W

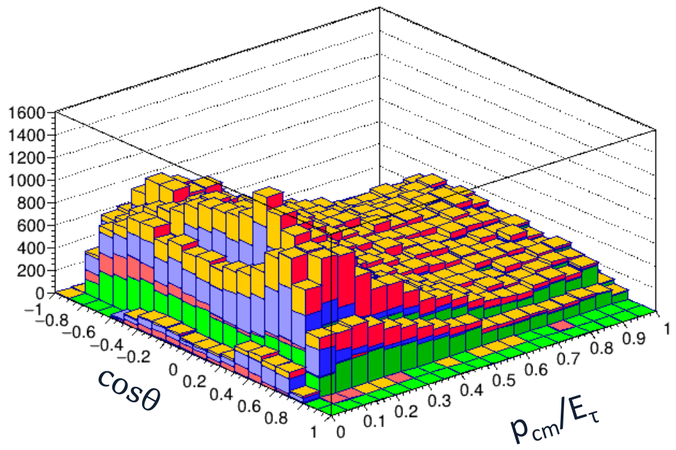
Template Example

- Templates for the tau MC

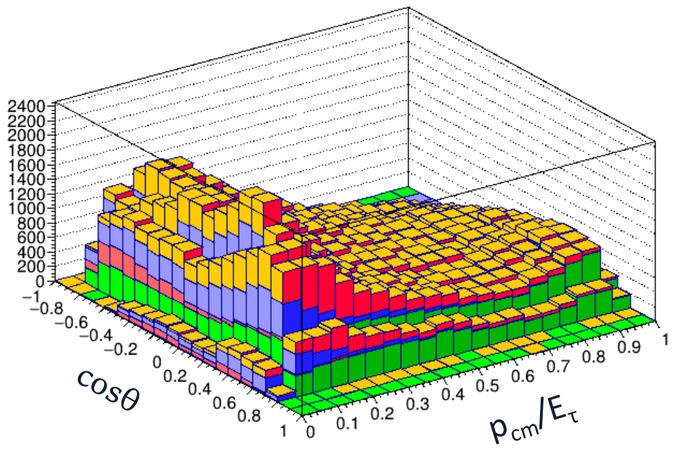
Left-handed e^- beam, π^- distribution



Unpolarized e^- beam, π^- distribution



Right-handed e^- beam, π^- distribution



$\tau \rightarrow \pi\nu$ $\tau \rightarrow e\nu\nu$ $\tau \rightarrow \mu\nu\nu$ $\tau \rightarrow$ else

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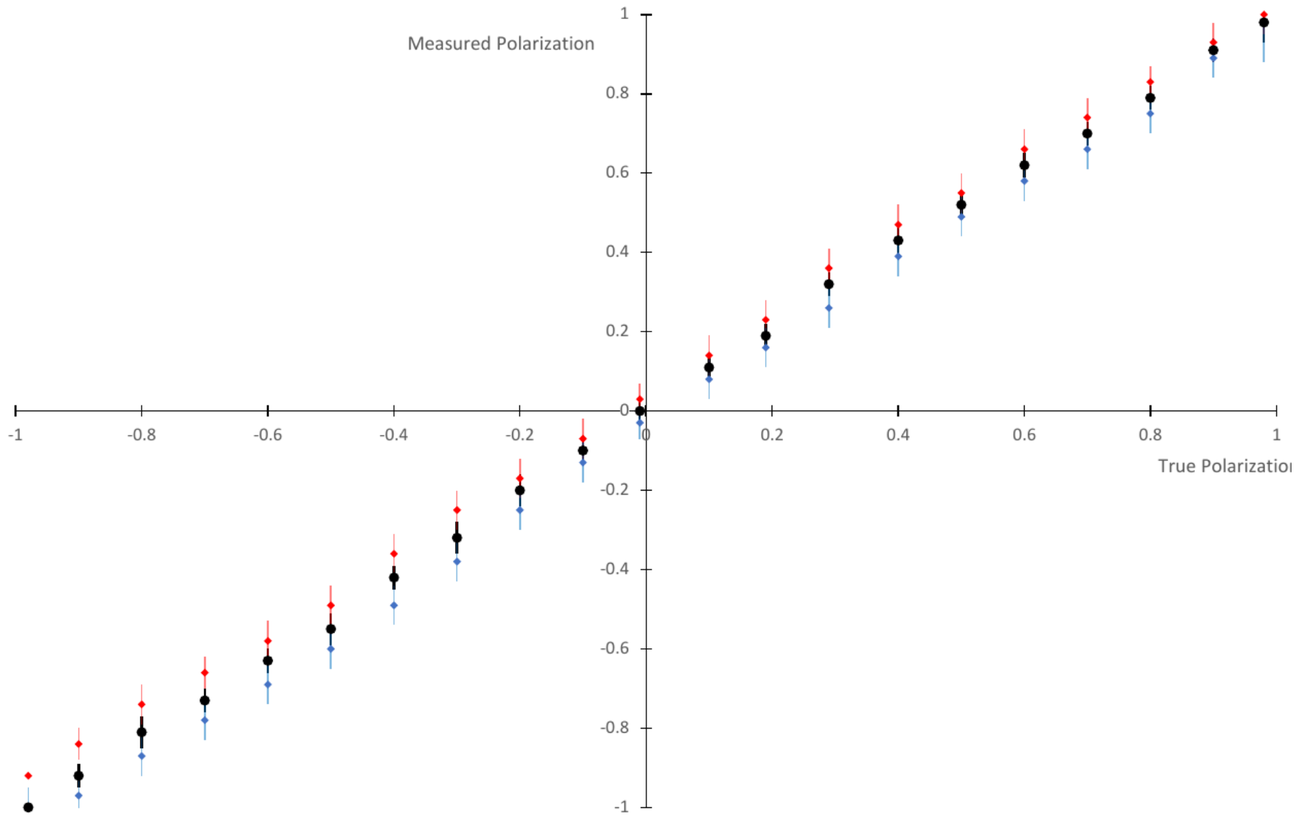
Absolute Polarization Sensitivity

- By mixing the polarized tau MC together, data-like samples with any beam polarization can be created and measured



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Fit Results and Systematic Uncertainties

	Positive Charge	Negative Charge	Combined Average
MC 1	-0.0064±0.0156	0.0093±0.0158	0.0013±0.0111
MC 2	-0.0018±0.0156	-0.0369±0.0158	-0.0191±0.0111
MC 3	-0.0038±0.0155	0.0036±0.0157	-0.0002±0.0110
Data	0.0258±0.0164	-0.0027±0.0167	0.0118±0.0117

BaBar beam polarization fit, 32.28 fb^{-1} study sample

Study	Systematic
Muon PID	0.0030
Neutral Clusters	0.0024
Momentum Resolution	0.0015
Electron PID	0.0012
BGFTau	0.0009
Other	0.0007
Total	0.0045

Summary of dominant systematic uncertainties

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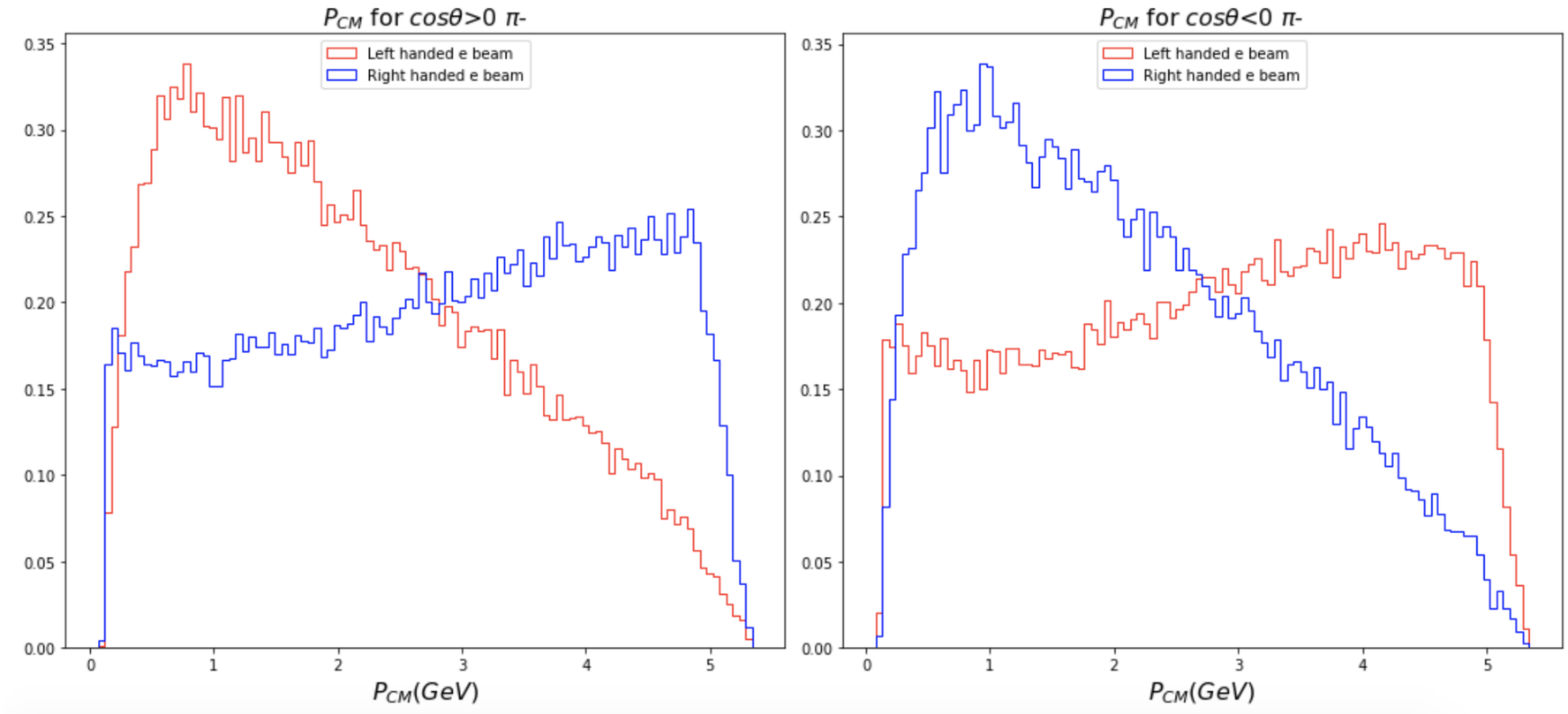
Belle II Initial Tests

- Started implementing this technique on Belle II
- Running KKMC with basf2 to confirm we see similar polarization sensitivity at Belle II



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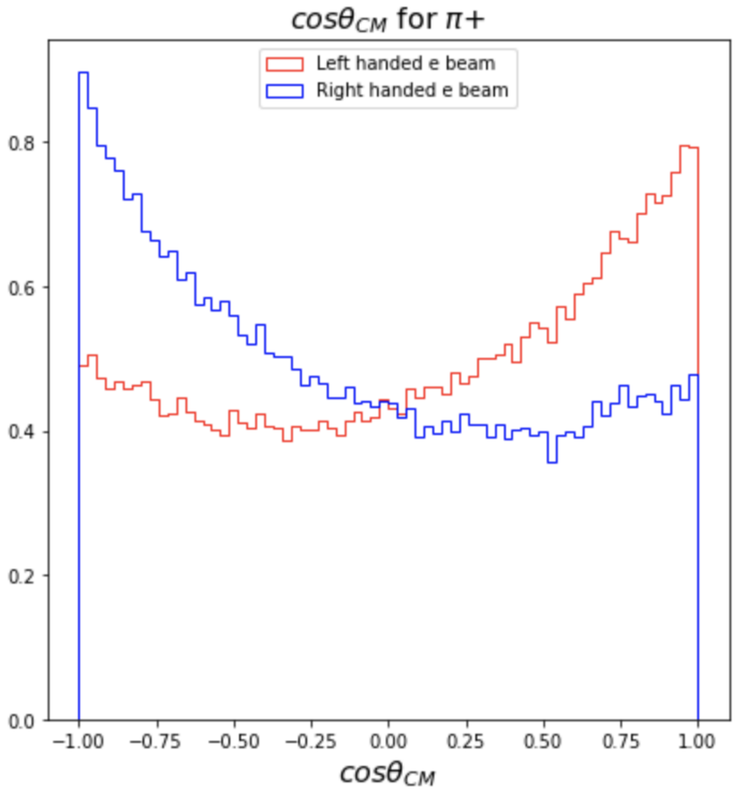

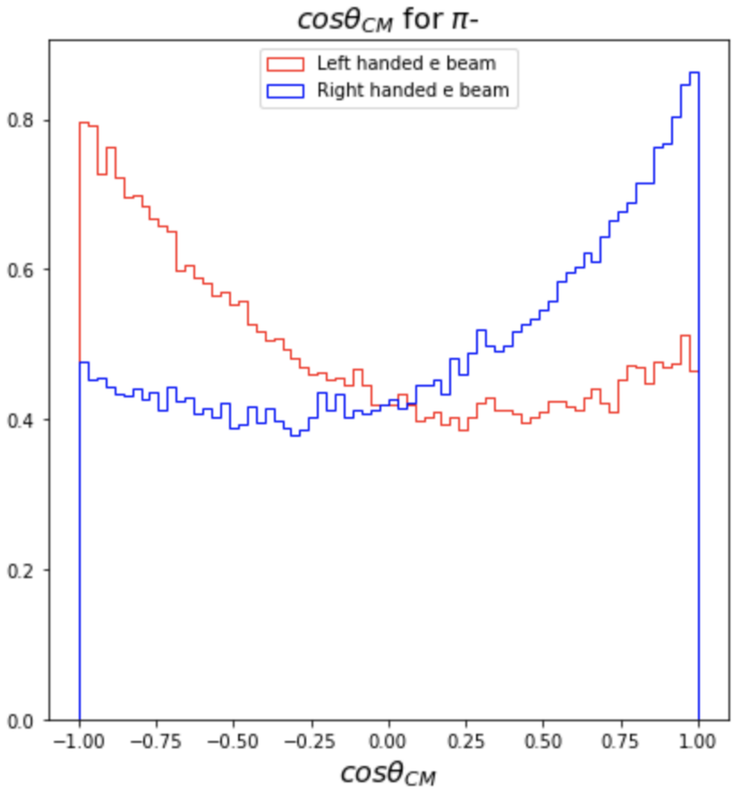

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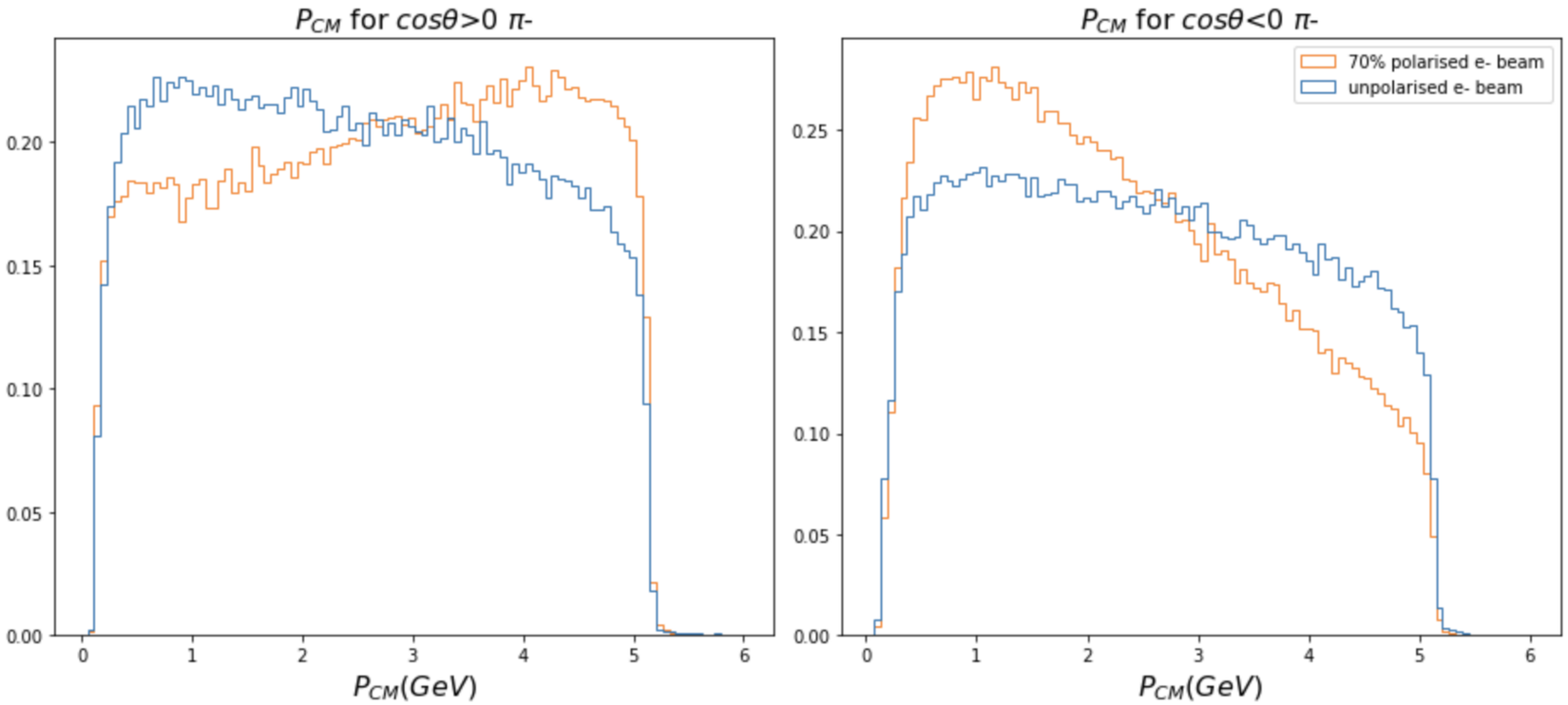
Belle II Initial Tests

- A small Belle II signal sample at 0.707 electron beam polarization was generated by Michel
- We see the effect is quite evident



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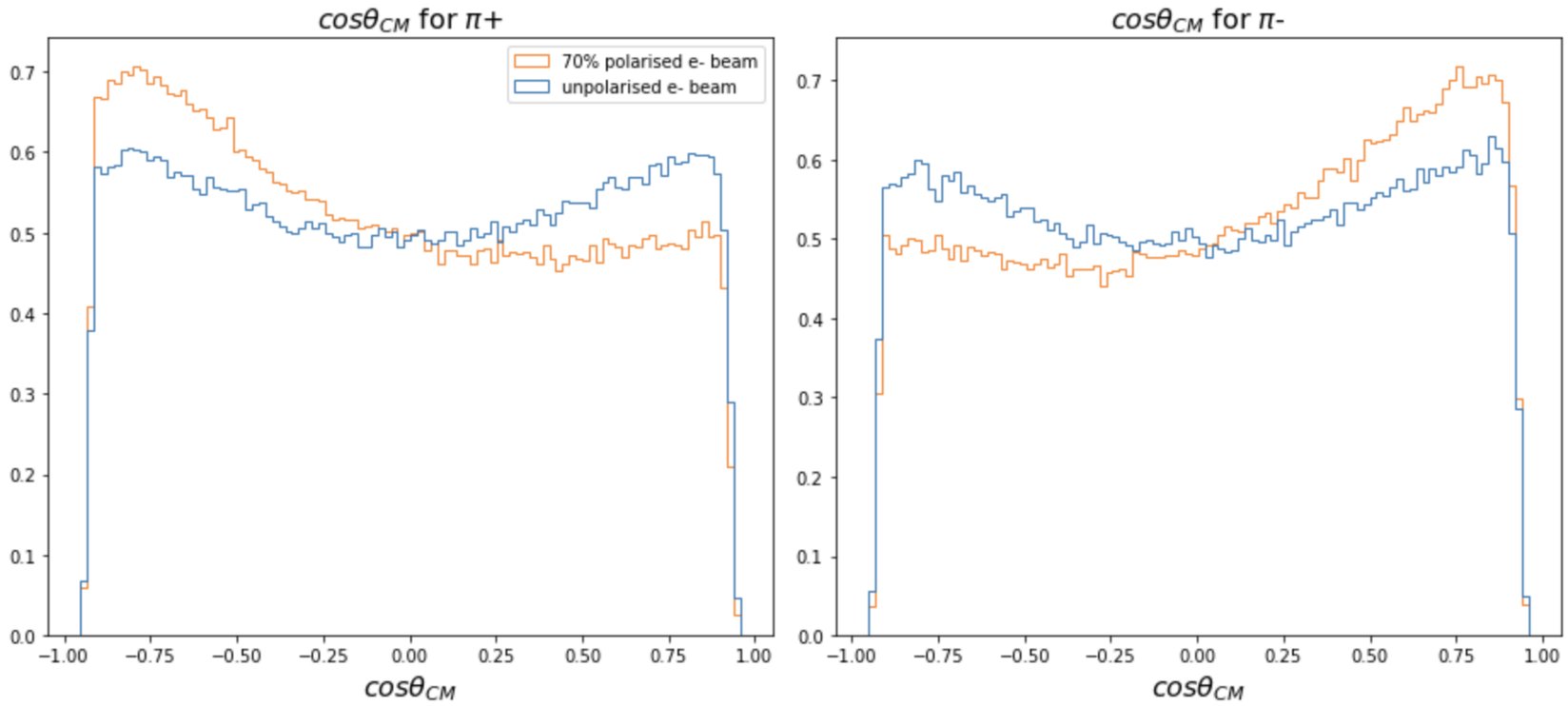

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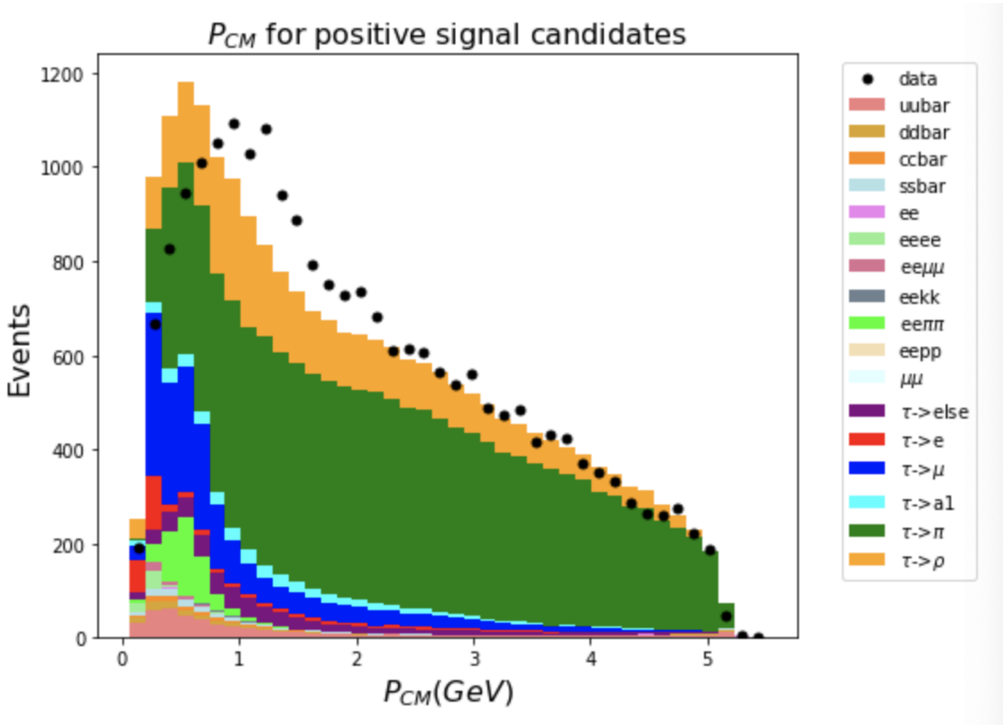
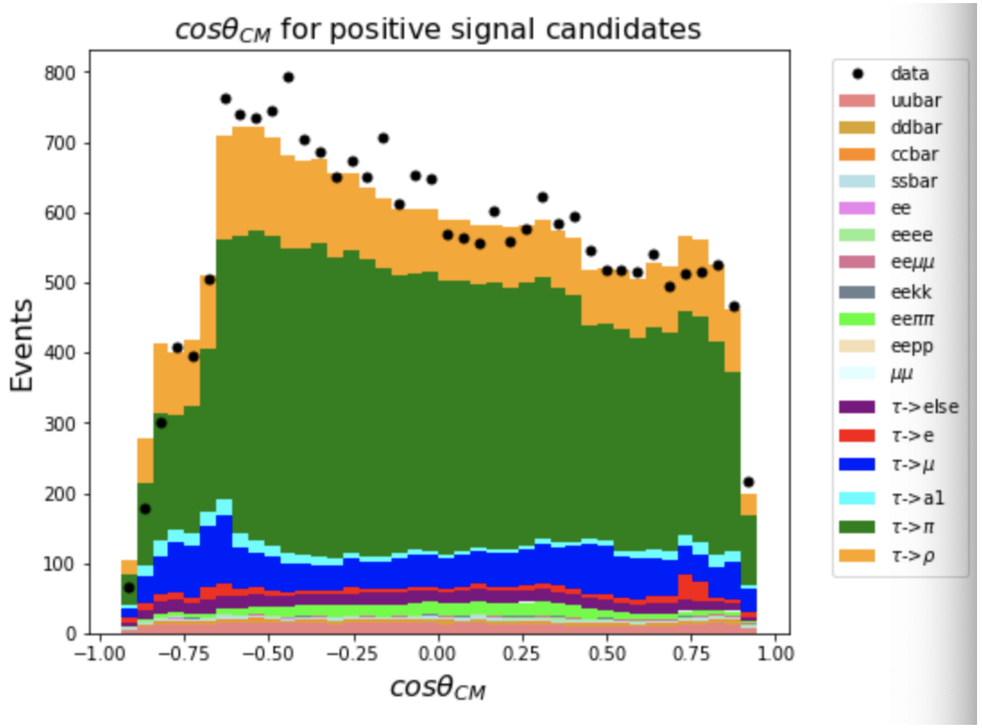
Belle II Initial Tests

- Started reproducing cuts on Belle II taupair MC
- Require 2 tracks, 2 photons with π^0 invariant mass
- Signal track is not muon or electron





Data and MC scaled arbitrarily for shape comparison. Not yet luminosity scaled

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Conclusions +Comments

- During the tau physics sessions, Denis Epifanov suggested the uncertainty in ξ (Michel parameter) may be a dominant systematic
- Currently we assume SM leptons, where the electron neutrino agrees to within 1E-4 and tau neutrino to 0. 7%
- Assuming universality we can use 1E-4, but new Belle II measurements on the universality would be helpful
- Proof of concept on BaBar is working well on study sample
- Dominant systematic uncertainties identified

$$\langle P \rangle = 0.012 \pm 0.012_{\text{stat}} \pm 0.0045_{\text{sys}}$$

- In the process of getting BaBar approval to study full dataset
- Initial implementation on Belle II being done by Dhwani Sutariya
- Signal MC request for polarized Belle II MC coming soon
- Investigating use of tau beam polarimetry at ILC

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